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A New Approach for Determining the Cost Allocation by Considering Transmission Line Mutual Inductance for Multilateral Contracts

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ABSTRACT

Addressing loss due to transmission and its cost allocation in deregulated electricity market is an essential issue. Independent System Operator (ISO) provides the active power loss from the generators and the associated cost is allocated to the concerned parties in a fair way. The generators and loads participate in the loss/cost allocation process. The highlight of the paper is that the effect of mutual inductance (MI) that exists on transmission line in transmission loss/cost allocation process for multlateral contracts is illustrated. To demonstrate the effect of mutual inductance, the results of existing loss allocation methods like penalized quoted cost (PQC) based approach are discussed. Effect of mutual inductance is presented using an IEEE 30 bus system. The simulation results are carried out using MATLAB R2014a. The result shows that mutual inductance has a significant impact on transmission loss and hence cannot be ignored.

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1. INTRODUCTION

The transmission network is a important mechanism in electricity markets, despite the fact that transmission charges represent a small percentage of operating expenses in utilities. In power system, the transmission network is where generators take part in supplying distribution companies and large users. Thus transmission pricing should be a reasonable economic indicator used by the electricity market to make resolution on allocation of cost, expanding the system, and strengthening the system. The markets of electricity requires entry to distribution and transmission networks that connects suppliers and customers as power flows has a impact on transmission charges, transmission pricing encourage efficiencies in electricity markets. A particular transmission pricing project which considers transmission restriction to motivate shareholder to build generating capacity and new transmission to strengthen the efficiency. Proper transmission pricing would meet income expectations encouraging a systematic operation of power markets, promoting investment in locations of generation, transmission lines and sufficiently reimburse owners of transmission benefits.

Moreover its difficult to achieve an efficient transmission pricing scheme that could fit all power markets in various places. The Independent System Operator would adjust particular timetables on a non-discriminatory basis to keep the system in the limit. Electrical power industry is experiencing significant changes brought by deregulation. Transmission losses, which used to be treated as an "extra load" by vertically integrated utility companies, have become a complicated quantity to allocate among system buses after deregulation. This is due to the fact that losses are expressed as a nonlinear function of line flows, making it impossible to exactly calculate the amount of loss caused by load, each generator or transaction

caused in system[1]. Multilateral transactions are usually long-term agreements determined through individual negotiation between a seller and a buyer. The price agreed upon a multilateral exchange is based on market forces and, other than under potential system security violations, thc levels of the multilateral transactions are arrived at any of centralised pool optimal dispatch. The reverse is not true, however, since the optimum pool dispatch must he coordinated with the predefined multilateral transactions. In this paper we are assuming that a set of multilateral contracts have been determined through some power exchange mechanism that facilitates such agreements. The question of economic efficiency of these contracts is not considered under the sensible supposition that when sellers and buyers reach a multilateral agreement, they do so because it is mutually beneficial [2]. Allocation of loss is a procedure for subdividing the system transmission loss into fractions, the costs of which then becomes the responsibility of individual users of the power systems (marketers, gencos discos). Loss allocation does not a impact on power flows or level of generation, however it does alter the distribution of revenues and payments at the network buses among consumers and suppliers [3].

2. RESEARCH METHOD

The suggested method is viable for normal operation of the power system. During congestion, the proposed PQC based approach is not fair and a separate procedure has to be followed like generation rescheduling to reduce congestion in the grid. Moreover, congestion occurs for a short period of time when compared to normal operation. The scope of this paper is restricted to normal functioning of the grid. This paper exhibits a novel loss allocation method in which losses are supplied economically by considering quoted cost and penalty factor of the generator. Quoted cost of the generator is penalized by incorporating penalty factor to account for distance between generator and load. Higher the penalty factor the higher is the real power loss supply from the specific generator. The proposed method ensures economic real power loss supply by ranking the loss supplying generators in the ascending order of penalized quoted cost. Cost allocation to the transaction is based on loss contribution fraction. This fraction is dependent on incremental transmission loss and quantum of real power transmission between generator and load. As the transaction charges are calculated based on real power, the reactive power demand of the load is ignored in the proposed approach. For an unbalanced transaction, slack bus is considered as the counterpart in meeting the losses. The proposed PQC based loss allocation approach has the following advantages

a. Loss or cost allocation to generators and loads are fair and it is non-negative.
b. It uses conventional AC load flow resulting in calculating real power losses.
c. Real power loss is economically shared between generators and loads.
d. Relative position of the buses is taken into account by considering the penalty factor.
e. Losses are allocated to individual transaction considering only the magnitude of real power for a given transaction.
f. Independent of size of the system and quantum of generation.
g. Understanding and implementation of algorithm is simple.

Impact of mutual inductance is incorporated in the loss or cost allocation process through bus admittance matrix. In this proposed approach, bus admittance matrix is computed by adding mutual elements in a manner similar to the methodology used for elements without mutual coupling. This effect changes the bus admittance matrix, voltages of the nodes, power flow through the lines and hence total losses of the network. Thus the change in transmission loss and its cost is allocated among the network buses.

$$Y_{bus} = A^T y_{prim} A \quad (1)$$

where, A- element–node incidence matrix and y_{prim} - primitive admittance matrix.

The dimensions of A and y_{prim} for a network with e elements and n nodes is $(e\times n)$ and $(n\times n)$ respectively.The primitive admittance matrix is rewritten and given as

$$y_{prim} = \sum_{i=1}^{e} \sum_{j=1}^{e} y^\wedge{}^{ij}_{prim} \quad (2)$$

where y_{prim}^{ij} – $(e \times e)$ matrix with only one non zero element. The position of non zero element is (i,j) and the value is equal to the value of y_{prim}^{ij}. Therefore equation (1) can be written as

$$Y_{bus} = A^T \sum_{i=1}^{e} \sum_{j=1}^{e} y^\wedge{}^{ij}_{prim} A \quad (3)$$

The y_{prim}^{ij} matrix is scalar as it contains only one non-zero element. The equation (3) can be written as

$$Y_{bus} = \sum_{i=1}^{e} \sum_{j=1}^{e} y_{prim}\,(i,j) A_j^T A_j \qquad (4)$$

In deregulated electricity market, for 'n' bus system with 'ng' loss supplying generators are participating in sharing the total real power loss by quoting their quoted cost. The penalized quoted cost [4] of the generator 'i' is given by equation (5)

$$PQC_i = L_i * QC_i \qquad (5)$$

The penalty factor has to be considered to rank the generators and hence to compute penalty factor, the loss function derived by Grainger and Stevenson in [5] is shown in equation (6).

$$P_{loss-ac} = \sum_{i=1}^{n_g} \sum_{j=1}^{n_g} P_{gi}\, B_{ij} P_{gj} + \sum_{i=1}^{n_g} B_{i0}\, P_{gi} + B_{00} \qquad (6)$$

For every change in generation of real power in generator 'i', incremental transmission loss is given by equation (7).

$$ITL_i = \frac{\partial P_{loss-ac}}{\partial P_{gi}} \qquad \text{for i = 1 to } n_g \qquad (7)$$

Then, the penalty factor is shown in equation (8).

$$L_i = \frac{1}{1-ITL_i} \qquad \text{for i = 1 to } n_g \qquad (8)$$

To allocate the cost of real power loss to the individual transaction, loss contribution fraction is computed from the dc loss function derived by Fred C. Schweppe et. al in [6] given in equation (9).

$$P_{loss-dc} = P_i^T\ [B_{mn}]\ P_i \qquad (9)$$

The transmission loss of transaction 'k' is given by equation (10).

$$L_k = L_{T_{i-j}} = \frac{\partial P_{loss-dc}}{\partial P_i} P_{gi} - \sum_{j \epsilon \alpha_k} \frac{\partial P_{loss-ac}}{\partial P_j}\, P_{dj} \qquad \text{for k= 1 to } n_{tr} \qquad (10)$$

Loss contribution fraction is obtained from the transmission loss due to transaction 'k' and it is given by equation (11).

$$f_k = \frac{L_k}{\sum_{k=1}^{ntr} L_k} \qquad (11)$$

To compute cost allocated for transaction 'k', overall cost for supply of loss is given in equation (12).

$$CT_k = f_k * TC_{ploss} \qquad (12)$$

Algorithm to determine cost allocation and loss contribution fraction

STEP 1: Calculate Penality Factor for each and every generator L_i
STEP 2: Calculate Quoted Cost QC_i from the given generator data
STEP 3: Determine Penality Quoted Cost by L_i and QC_i
STEP 4: Compute Real Power Transmission Loss of transaction K (L_k) from equation (6)
STEP 5: Determine Loss Contribution Fraction (f_k) which is obtained from the Real Power Transmission Loss Due to transaction K from equation (7)
STEP 6: Calculate Cost Allocation to transaction k from equation (8)
STEP 7: Assume 5% of average reactance as Mutual Inductance value between two lines.

STEP 8: Compare Loss Contribution Fraction and Cost Allocation values With Mutual Inductance and Without Mutual Inductance. There is 3.42 % increase in Cost and Losses in each bus when Mutual Inductance is considered.

3. RESULTS AND ANALYSIS

The impact of mutual inductance is demonstrated using a 30 IEEE bus system. It consists of 41 transmision lines, 6 generators and 20 loads. Respective fuel cost equations are assumed as quoted cost of the generators [7]. The additional available capacity is assumed as 1 MW. Generator data and transaction data is given in Table 6 and Table 7 respectively.18 multilateral transactions are considered for this system as shown in Figure.1. The two cases, namely, with and without considering the mutual inductance are discussed in this test system. The mutual inductance value is computed from the reactance value of the line.

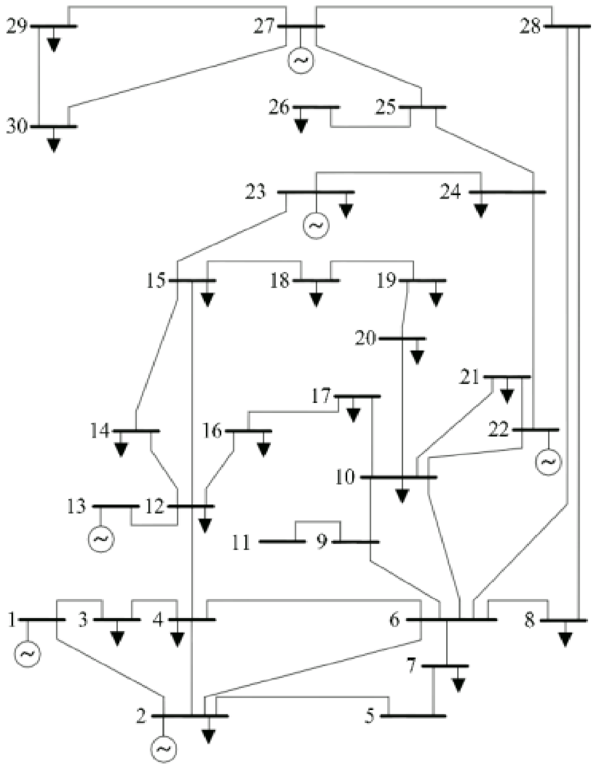

Figure.1. 30 IEEE bus system

The average reactance of two lines is calculated and 5% of average reactance is assumed as mutual inductance. The assumed mutual inductance value between the two lines is given in table 1. 200$/MWhr is the incremental cost for loss. Table 1 shows mutual inductance data. Table 2 shows generator data of 30 IEEE bus system. Table 3 shows transactions data of 30 IEEE bus system. Table 4 shows economic loss allocation schedule of 30 IEEE bus system.

Table 1. Mutual Inductance Data

S.NO	Between lines	Mutual inductance
1	1-2 & 1-3	0.0065
2	1-2 & 2-4	0.006
3	1-3 & 3-4	0.006
4	2-4 & 3-4	0.0055
5	2-5 & 5-7	0.0035
6	2-6 & 4-6	0.0055
7	5-7 & 6-7	0.005
8	6-8 & 8-28	0.00725
9	6-9 & 9-11	0.0105
10	9-10 & 10-17	0.005
11	12-13 & 12-14	0.01
12	12-14 & 14-15	0.0095
13	14-15 & 15-23	0.01175
14	12-16 & 16-17	0.00775
15	16-17 & 10-17	0.007
16	15-18 & 18-19	0.00875
17	18-19 & 19-20	0.005
18	19-20 & 10-20	0.007
19	10-21 & 21-22	0.0075
20	21-22 & 22-24	0.01
21	15-23 & 23-24	0.012
22	24-25 & 22-24	0.01275
23	25-26 & 25-27	0.01475
24	27-28 & 27-29	0.02
25	27-28 & 6-28	0.0115
26	27-29 & 29-30	0.02125

Table 2. Generator Data of 30 IEEE Bus System

GENERATOR BUS NO.	GENERATOR COST COEFFICIENTS			QUOTED COST($/MWhr)
	a	b	c	
1	0.0070	7.0	240	247
2	0.0095	10.0	200	210
13	0.0090	8.5	220	228.5
22	0.0090	11.0	200	211
23	0.0080	10.5	220	230.5
27	0.0075	12.0	190	202

Table 3. Transactions Data of 30 IEEE Bus System

GENERATORS BUS NO.	LOAD BUS NO.	ACTIVE POWER TRANSACTION (MW)
1	7	22.8
2	12,3,4	30,2.4,7.6
5	24,23	3.5,8.7
8	30,26,29	10.6,11.2,2.4
11	21,10,20	2.2,3.2,9.5
13	19,18,17,16,15,14	17.5,5.8,9.0,3.5,8.2,6.2

Table 4. Economic Loss Allocation Schedule of 30 IEEE Bus System

Generators Bus No.	Penalty Factor	Penalized Quoted Cost ($/MWhr)	Ranking Of Generators	Supplied Quantity For Loss (MW)	Cost Of Supply Of Loss ($/hr)
1	1.0471	258.63	6	-	-
2	1.0405	218.50	3	1	210
5	1.0338	236.22	4	0.124	28.33
8	1.0223	215.70	2	1	211
11	1.0323	237.94	5	-	-
13	1.0491	211.92	1	1	202
	Total			**3.124**	**651.33**

In PQC method, the overall cost associated with supplying of loss is allocated to the individual transaction on the basis of loss contribution fraction as shown in Table 5.

Table 5. Allocation of Cost to Individual Transaction

Generator to load bus no.	Real power P (MW)	Loss contribution fraction		Cost allocation ($/hr)	
		Without MI	With MI	Without MI	With MI
1-7	22.8	0.0485	0.0501	31.623	32.696
2-3	2.4	0.0057	0.0058	3.7003	3.826
2-4	7.6	0.0228	0.0235	14.881	15.387
2-12	30.0	0.0510	0.0527	33.208	34.344
5-23	8.7	0.0866	0.0895	56.411	58.340
5-24	3.5	0.0305	0.0315	19.865	20.534
8-26	11.2	0.2583	0.2671	168.257	174.0007
8-29	2.4	0.0243	0.0251	15.850	16.391
8-30	10.6	0.1433	0.1482	93.332	96.523
11-10	3.2	0.0028	0.0028	1.8122	1.8741
11-20	9.5	0.077	0.0799	50.354	52.076
11-21	2.2	0.0035	0.0035	2.2655	2.263
13-14	6.2	-0.0004	-0.0004	-0.2650	-0.274
13-15	8.2	0.035	0.0356	22.441	23.208
13-16	3.5	0.0001	0.000103	0.0583	0.060
13-17	9.0	0.0067	0.00692	4.383	4.533
13-18	5.8	0.047	0.0482	30.403	31.443
13-19	17.5	0.158	0.1632	102.778	106.293
Total		**1.00**	**1.00**	**651.33**	**651.33**

4. CONCLUSION

This paper presents the impact of mutual inductance on transmission loss/cost allocation process for multilateral contracts.Loss allocation method like PQC method is presented to demonstrate the result. The results of 30 IEEE bus system shows that the mutual inductance has a significant impact on transmission loss/cost allocation and hence cannot be neglected. The losses are increased due to the mutual inductance and

the associated cost can be recovered from the generators and the loads of the network. Hence the impact of mutual inductance on transmission loss has considerable effect on its cost allocation. The results obtained are reasonable as it uses loss contribution fraction for cost allocation to individual transaction. The result shows that the proposed method has significant impact on cost allocation as it equally allocates the cost to loads and generators. As this approach is based on the quoted cost given by the generators to participate in loss allocation process it can be claimed as the fairest among the existing methods

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